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STUDY OF THE EFFECT OF SATURATING COAL SAMPLES WITH “THE SHTAMEX” FOAMING AGENT SOLUTION ON THEIR OUTBURST HAZARD INDICATORS

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Abstract. The article presents the results of studies on the mechanical parameters of coal samples from seam d_4 of the PJSC Pokrovske Mine Administration in their supplied state and after treatment with “the Shtamex” foaming agent solution. The studies showed that these coal samples exhibited very high outburst hazard compared to other samples from the same seam. In addition, they had abnormally high water permeability. Deformation curves were obtained, which express the relationship between mechanical stresses and deformations under uniaxial compression of cubic-shaped samples with an edge length of 40 mm and a central hole with a diameter of 6 mm. The holes were drilled perpendicular to the layering of the samples. Their loading was applied in the same direction. The modulus of elasticity (yield) of dry samples was assessed by deformation curves with a limited load of not more than 5 MPa - at the level of 30–40% of the expected maximum. The load limitation minimized the effect of sample integrity disruption due to the beginning of the cracking process. The yield of dry samples was assessed by the deformation curves under the full load of the same samples. The full load included the stress increase phase, the transition through the temporary strength limit and the stress drop phase up to the destruction of the samples. The outburst (impact) safety factor was calculated as the ratio of the modulus of elasticity to the modulus of stress drop beyond the temporary strength limit. The abnormally high water permeability of the samples made it impossible to saturate them with “the Shtamex” solution using the standard IGTM’s methodology under the mode of two-dimensional flow filtration from the periphery to the central hole. Instead, saturation was performed by a less perfect method - holding the samples under an excess pressure of 0.15 MPa for 45 minutes. During this holding period, 2–3 short-term discharges of part of the solution mixture were made through the central hole of the sample and the drainage channel. It was established that saturation of the samples with “the Shtamex” solution reduces the modulus of elasticity, i.e. increases the coal yield. In this regard, the effect of “Shtamex” is similar to the effect of water, traditional SAAs and emulsions. However, the increase in yield is at least 1.3 times higher from “Shtamex” than the increase from water, traditional SAAs and emulsions. Just like water, traditional surfactants and emulsion, “Shtamex” increases the outburst safety coefficient. The increase in outburst safety at a 3% concentration of “Shtamex” is at the level of water and traditional SAAs, whereas at a 6% concentration of “the Shtamex”, it becomes almost twice as effective as them.

Keywords: yield, temporary strength limit, modulus of drop, outburst hazard.

1. Introduction

The extraction of outburst-prone and fire-hazardous coal seams, especially at great depths, remains one of the most serious and unresolved issues of safe coal mining [1–3]. This largely concerns coal, rock and gas outbursts [4, 5], methane and coal dust explosions, and fires [6–8]. Currently, a great number of methods are known for predicting and combating explosions, fires and especially gas-dynamic phenomena, taking into account the presence of free and bound gas [4, 9–11]. These include drilling of advance boreholes, pressure release through the cracks, degassing, water injection into the seam, and others [12–15]. However, gas-dynamic phenomena continue to occur during mining operations, resulting in people death and significant economic losses to mines [16–19]. Therefore, studying the mechanisms and processes of outburst occurrences remains a highly relevant task. In this work, the authors primarily focus on investigations related to water injection into coal seams.

The prevention of sudden coal outbursts is based on the injection of water under high pressure through boreholes drilled into the coal seam. The widespread use of water injection began in the sixties of the last century. At that time, water injection was considered as a comprehensive measure that reduced dust formation and pre-

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vented sudden coal outbursts [20, 21]. As a result, recommendations were developed and included in regulatory documents [15, 16, 22] regarding the feasibility of adding SAAs (surface-active agents) to the water. The addition of SAAs improve the permeability of the liquid into small cracks and pores of the seam, contributes to its more uniform moistening, and, purportedly, reduces the resistance of the seam to solution injection [22, 23].

Since then, there have been fundamental changes in the use of preventive measures in coal mining. In Ukrainian mines, the practice of moistening seams through long boreholes drilled into seams to prevent dust formation has been discontinued [24]. This is because it is either impossible or extremely difficult to ensure drilling of boreholes of the required length 150 m to effectively treat a modern longwall face with standard length 300 m.

Today, hydraulic treatment of seams is used exclusively for preventing sudden outbursts and is carried out through shot holes in hydro-loosening mode [1, 15]. For this technology, the key effects are weakening and unloading the seam from excessive rock pressure in the local treatment zone, and reducing its impact hazard [25]. In addition, new fire retardants and foaming agents [26, 28] are now being used, many of which have similar effects on coal as traditional SAAs. Therefore, they can be used not only for their direct purpose - fire prevention and suppression - but also for prevention sudden coal outbursts.

Therefore, the Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine) is conducting research into the effectiveness of using fire retardants and foaming agents to change the deformation properties and impact hazard of coal.

The purpose of this article is to study the effect of the Shtamex foaming agent solution on the change in the deformation properties and impact hazard of coal from seam d_4 of the Pokrovske Mine Administration.

2. Methods

The experiments were planned according to the testing program developed at the IGTM of the NAS of Ukraine, which includes:

- Preparation of coal samples with dimensions of 40×40×40 mm and a central hole with a diameter of 6 mm. The central hole is necessary for saturating the samples with fluid in a two-dimensional flow mode from its periphery to the center. This saturation scheme best corresponds to the conditions of saturation of a real seam by liquid [20, 27].
- Obtaining of limited deformation curves for dry samples under uniaxial compression using a load not exceeding 5 MPa - representing 30–40% of the expected maximum. The load limitation minimized the effect of sample integrity disruption due to the beginning of the cracking process [27].
- Obtaining of full deformation curves for saturated and reference dry samples under uniaxial compression to determine their temporary strength limit, modulus of drop beyond the strength limit and impact hazard coefficient.

The impact hazard coefficient is calculated using a formula established by the Ukrainian Research Mine Surveying Institute [15, 22] and generally accepted during the Soviet times:

$$K = \frac{E}{M}, \tag{1}$$

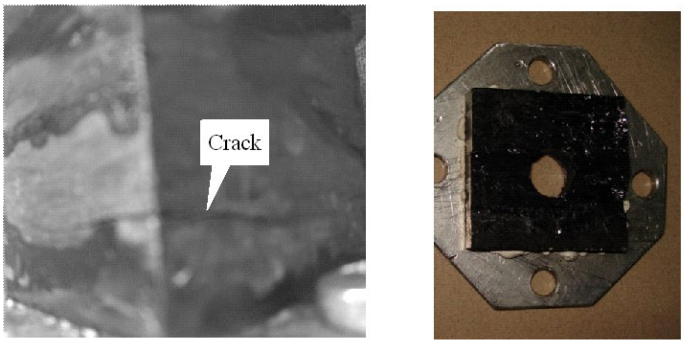
where E is the modulus of elasticity of the sample in the area of ascending stresses of the deformation curve; M is the modulus of drop in the area of descending stresses of the deformation curve after the temporary strength limit.

Both the moduli of elasticity and drop were determined by the coefficients of linear approximation of ascending and descending areas in the graphs of deformation curves.

A total of 16 coal samples from the seam d_4 of the Pokrovske Mine Administration were prepared. One of these samples, which initially had no visible cracks, developed a transverse crack during its drilling with a standard Ø 6mm drill (fig. 1-a). This crack, when the sample was broken by hand, separated the lower part of the sample from the upper part (fig. 1-b). This was the first sign of increased brittleness of the samples, since this had not been observed before.

Several other samples developed much smaller cracks along the hole during drilling. Apparently, this circumstance led to the fact that 2 samples, after moistening with a 6% solution of Shtamex, split in the hands along the hole immediately after their removal from the chamber with the solution.

Three samples experienced localized chipping under limited loading in a dry state, which made it impossible to obtain correct comparative characteristics during their subsequent loading.



a) b)

a) section formed by the transverse crack in the edge of the sample; b) separation of the sample along the crack plane as a result of breaking it by hand

Figure 1 – View of one of the coal samples damaged during drilling of the central hole

Given this circumstance, it was decided not to subject the remaining samples to limited loading, and, instead, to make the conclusions regarding the effect of SAAs on the deformation characteristics based on the first 3 samples.

The sample saturation, which is standard for the IGTM, namely, with liquid in the mode of two-dimensional filtration under constant pressure with determination of the change in its flow rate over time, also failed to be carried out. An attempt to moisten the first three samples with water showed that their permeability was too high for measurements using the developed method and the available equipment. At a very low excess pressure of ≈ 0.15 bar, the flow rate through the sample exceeded 1 cm^3/s.

It became clear, firstly, that it was technically impossible to measure filtration characteristics of the solutions Shtamex, Pirocool and water-oil emulsion, which were available in limited quantities, on such fractured coal. And secondly, the inexpediency of such measurements, because they would in no way reflect the real permeability of the coal samples for different solutions, but, instead, would reflect only the throughput of cleavage cracks.

The presence of such an extensively developed system of cleavage cracks did not allow normal impregnating of the entire volume of the sample with the solution when saturating it by the filtration flow of liquid under pressure. The entire flow was concentrated in the cleavage cracks, and almost nothing remained for the porous material.

Therefore, it was decided to change the sample saturation method [22, 28] to a less perfect method [25]. Instead of the free flow of liquid through the sample, the method involved immersion of the sample in liquid inside the chamber of the two-dimensional filtration test bench and holding it under an excess pressure of 1.5 bar for 40 minutes. During this holding period, 3–4 short-term discharges of the gas-air mixture with the solution were performed via the drainage valve. Despite the imperfection of this saturation method, the moisture content of the samples increased by 0.7-1%. And this made it possible to assess the effect of saturation with a 6% “the Shtamex” solution on the increase in the yield of coal samples and the reduction of their impact hazard, as well as the effect of saturation with a 3% “the Shtamex” solution only on the reduction of impact hazard.

Thus, the completely atypical brittleness and permeability of the samples significantly reduced the scope of the test program, which was ultimately limited to:

- Obtaining of limited deformation curves for 3 dry samples under uniaxial compression.
- Obtaining of full deformation curves for 3 samples saturated with a 6% “the Shtamex” solution under uniaxial compression, for 3 samples saturated with a 3% “the Shtamex” solution, and for 3 reference dry samples. Nevertheless, the results of these limited tests are considered to be of serious scientific interest.

3. Results and discussion

Comparative deformation curves for samples No. 2 and No. 3 under limited uniaxial compression are shown in figure 2, 3. The upper curves refer to samples treated with 6% solution of the additive “Shtamex”, the lower ones refer to dry samples. Comparison for sample No. 1 could not be obtained due to malfunction of the displacement recording channel during its testing after saturation with the solution.

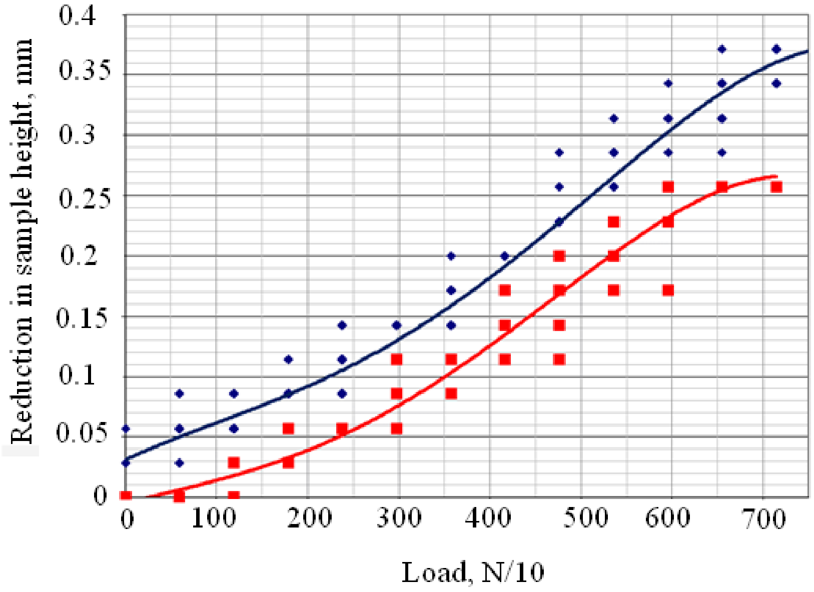


Figure 2 – Deformation curves for sample No. 2 treated with a 6% “the Shtamex” solution

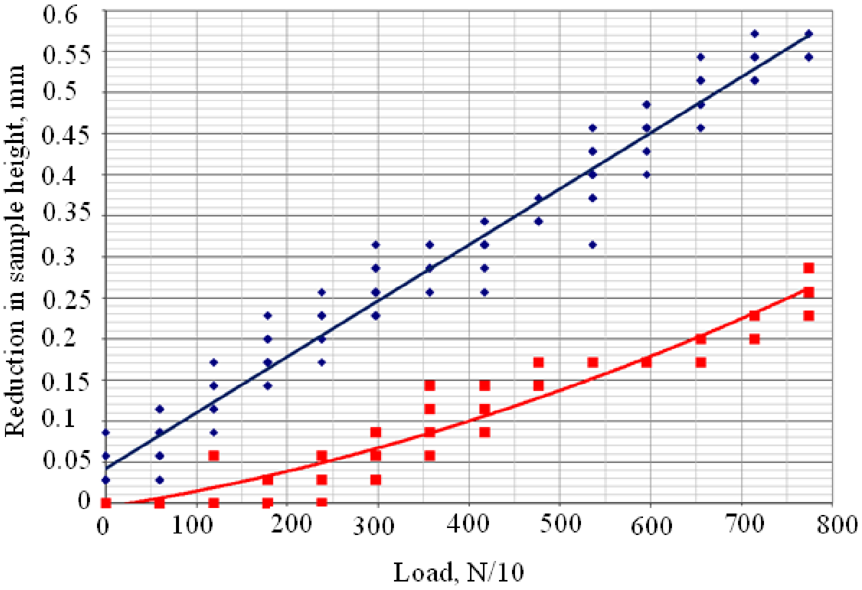


Figure 3 – Deformation curves for sample No. 3 treated with a 6% “the Shtamex” solution

Figure 2 and 3 clearly illustrate the increase in the yield of both samples after their treatment with 6% “the Shtamex” solution with the same humidity increase of ΔW = 0.7%. For example, under a load of 7000 N (700 kG) on dry sample No. 3, its height decreased by ≈ 0.23mm, while the height of the moistened sample decreased by ≈ 0.52 mm (i.e. twice as much) under the same load of 7000 N.

The difference in the height reduction of dry (≈ 0.26mm) and moistened (≈ 0.36mm) sample No. 2 under the same load of 7000 N is evidently smaller (≈ 1.4 times), but the trend is the same.

Moreover, this trend coincides with the results of previously performed studies on saturation of coal from the same seam d_4 of the Pokrovske Mine Administration, but from earlier batches, after it had been treated with emulsion from the hydraulic system of powered support. The same effect was observed during water saturation of a sample from the “Krasnolimanska” mine, under varying moisture increments ΔW (fig. 5).

These samples had typical low coal permeability, so they were saturated using a more advanced standard method of the IGTM of the NAS of Ukraine with a two-dimensional liquid flow from the periphery to the central hole.

The corresponding graphs are shown in fig. 4 and 5. The vertical axis shows the longitudinal deformations of the samples ε, %. The horizontal axes show the longitudinal stresses σ, MPa.

In fig. 4, the lower curve corresponds to the dry sample deformation, and the upper curve corresponds to the deformation of the same sample after its saturation with an emulsion.

In fig. 5 the lower curve marked ΔW = 0% corresponds to the dry sample, the upper curve marked ΔW = 2% - to the same sample after an increase in its humidity by 2%.

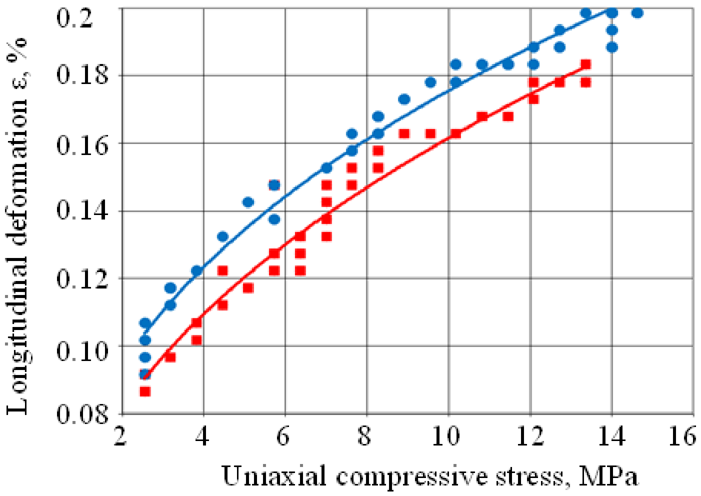


Figure 4 – Deformation curves for sample No. 3 treated with emulsion

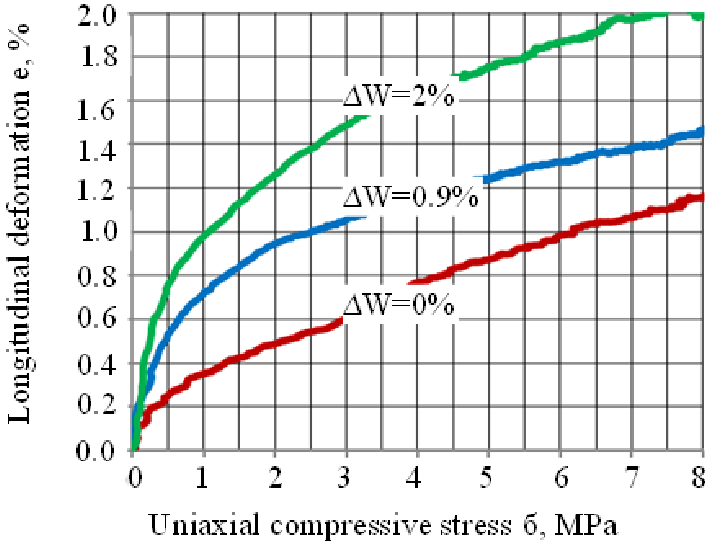


Figure 5 – Deformation curves for the sample at different water saturation

The effect of moistening with water on deformation at the same stresses (yield) is the same as when moistening with solutions – yield increases, and the increase due to "the Shtamex" is 1.3–2 times greater than the increase from water (1.3 times at the same humidity increase) and from emulsion (1.3 times).

Yet, one can observe a certain difference in the shape of the deformation curves for water (fig. 4) and emulsion (fig. 3) with "the Shtamex" solution (fig. 1, 2). The curves in fig. 4 and 5 are convex, while the curves in fig. 2 and 3 are concave. This can be explained either by the influence of the composition of chemicals in the solutions, or by different properties of coal, because properties of the coal used for treating with "the Shtamex" differed significantly from coal from the same coal seam, which had been received from the mine in previous times.

To clarify this issue, additional research will be required. However, in our opinion, the difference in the shape of the deformation curves is due to the specific properties of the coal of the last batch. Our opinion is supported by the results of studies of the destruction of samples under uniaxial compression, which are given below.

Each sample was subjected to uniaxial compression until complete destruction using a press equipped with apparatus for digital recording of the load on the lower plate and its movement. The recorded signals were processed by the program "Excel" with linear approximation of the ascending and descending segments, which allowed for the construction of experimental deformation curves, one of them is shown in fig. 6.

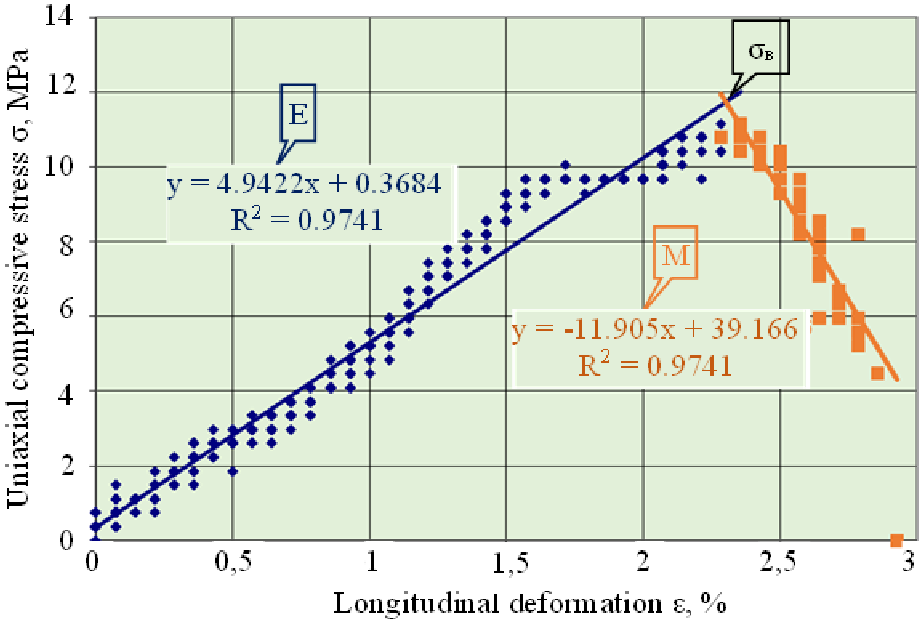


Figure 6 – The curve of complete deformation of the sample

They were used to determine the temporary strength limit σ_t (MPa), the modulus of elasticity (E/100), MPa, and the modulus of drop (Ed/100), MPa, for each sample. Based on the values of E and M, the impact safety coefficient was calculated using the formula presented at the beginning of the article. Traditionally, the coefficient in this formula is referred to as the impact hazard coefficient. However, according to the content of the formula, it actually reflects safety rather than hazard. This is because the modulus of drop M in the denominator of the formula is always greater than the modulus of elasticity E, which appears in the numerator, for brittle rocks. An ideally dangerous rock would clearly be an absolutely brittle rock, for which $M \to \infty$ and $K \to 0$. And, conversely, an ideally safe rock would be a plastic rock, for which $M \to 0$ and $K \to \infty$.

That is, the greater is the coefficient K, the safer is the rock. The safety margin is the value of $K = 1$; all rocks with $K < 1$ are dangerous. And the smaller is K, the less safe the rock is in terms of factors of a mining impact or sudden outburst. Therefore, we will use the term “impact safety coefficient” both in table 1 and hereinafter in this article.

Table 1 – Mechanical characteristics of coal samples

Sample №	1	2	3	4	5	6	7	8	9
Shtamex water solution concentration, %	6	6	6	3	3	3	0	0	0
Temporary strength limit, σ_t, MPa	20.,8	19.4	10.8	11.9	10.4	11.2	10.8	9.3	29.4
Modulus of elasticity (E/100), MPa	-*	7.2	4.8	6.5	3.4	4.9	3.6	3.4	8.6
Modulus of drop (M/100), MPa	-*	21.1	5.1	35.8	30	11.9	25.4	20	46.4
Impact safety $K = E/M$	-*	0.3	0.9	0.2	0.1	0.4	0.1	0.2	0.2
Number of loading cycles	2	2	2	1	1	1	1	1	1

* – malfunction the displacement recording

The last row of the table shows the number of loading cycles for each sample. The first 3 samples were subjected to two cycles, one of which was limited by the magnitude of compressive stresses $\sigma \approx 4.5$ MPa, which is significantly (2–4 times) lower than the ultimate strength of these samples. These loadings were carried out to assess the change in the elastic modulus at the initial stage of deformation of the treated sample compared to the untreated one, as described in the methodology (section 2). The remaining samples were subjected to a single cycle of loading - until complete destruction. It’s possible that the difference in the number of loading cycles to some extent affected the final characteristics of the first three samples. However, studies conducted earlier by many authors do not give us grounds to consider this effect significant, and we do not take it into account.

For better visual illustration of the data from table 1, below are bar charts of the temporary ultimate strength σ_t for all tested samples. The column colors in the table and in the bar charts in fig. 7 coincide.

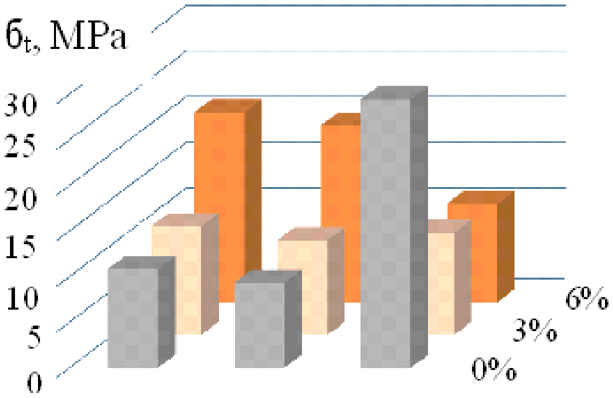


Figure 7 – Temporary strength limit σt of samples treated with Shtamex solution at concentrations of 6% and 3% and dry samples (0%)

It seems that the treatment of samples with Shtamex solution leads to their certain strengthening.

At the same time, all previously conducted studies by various authors reported a reduction in the strength limit after coal treatment with both ordinary water and solutions of various SAAs. It is possible that “the Shtamex” solution actually gives such an atypical effect. However, the samples selected for treatment with the solution were chosen based on their minimum fracturing. Most likely, these samples had noticeably higher strength even in the dry state. Therefore, the reduction in the strength of the six saturated samples might simply not have compensated the initial difference compared to the three untreated samples.

Figure 8 shows the impact safety coefficients of the samples before and after treatment with “the Shtamex” solution.

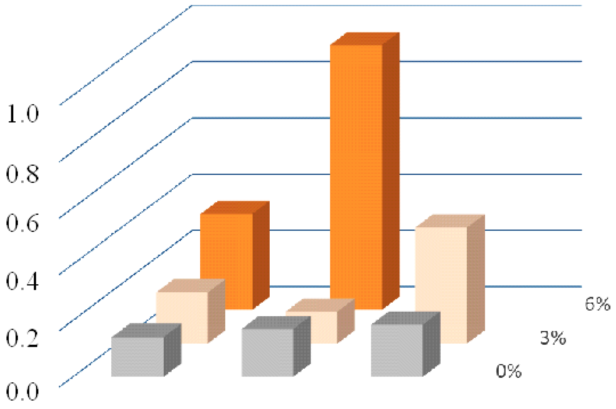


Figure 8 – Impact safety coefficients of coal samples treated with Shtamex solution at concentrations of 6% and 3% and dry sample (0%)

As we can see, all tested samples in their natural state had a rather low safety outburst coefficient, because for three untreated samples the average value of the coefficient is K = 0.17. When treated with 3% “the Shtamex” solution, the outburst risk increased slightly, because K rose to 0.24. And the most pronounced effect was observed at treatment with 6% “the Shtamex” solution, i.e. this concentration significantly reduced the outburst hazard, although it did not eliminate it entirely, because it increased the average K only to 0.64, and did not reach the safety outburst limit, which is equal to 1.

In this regard, the effect of reducing the outburst hazard with “the Shtamex” solution exceeded traditional SAAs based on PAA and DB substances (polyacrylamide PAA and polyethylene glycol ether of ditert-butylphenol DB)

The indicators of increasing the outburst safety for traditional SAAs were determined in earlier studies [25] and by a different criterion – energy-based criterion A. This criterion is based on comparing the work spent on compressing the sample in the area of ascending stresses with the work in the area of descending stresses. It is more labor-intensive than criterion K, as it requires additional calculation of the areas under the multi-colored segments of the deformation curve fig. 6, but is considered more accurate. However practice shows that significant differences in the results of applying these criteria are observed only in ≈ 20% of cases. And given that discrepancy between the indicators is typically 2–3 times for coal samples, this increase in accuracy is not at all relevant.

So, we have every reason to compare the effectiveness of “the Shtamex” solution (table 1) with that of traditional SAAs (table 6 in work [25]) in terms of influencing on the impact safety indicators, despite the use of different evaluation criteria.

Figure 9 shows an increase in the impact safety coefficients of the samples treated with water and traditional SAAs - polyacrylamide PAA and polyethylene glycol ether of ditert-butylphenol DB, compared to untreated ones.

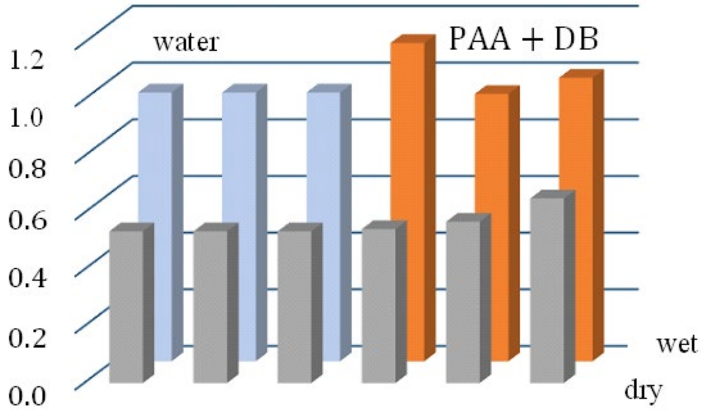


Figure 9 — Impact safety coefficients of samples treated with water, PAA+DB solution, and dry samples (first row)

At first glance, the use of traditional SAAs is more effective in terms of increasing impact safety than the use of “the Shtamex” solution. Their corresponding coefficient lies in the range of 0.9–1.1, and for “Shtamex” it ranges within 0.3–0.9. If we consider that the impact safety limit is 1, then traditional SAAs as well as mine water, practically eliminate impact hazard, while “the Shtamex” does not.

However, it should be noted that the dry coal samples in experiments with water and traditional SAAs were significantly safer than those in experiments with “Shtamex”.

Although coal for experiments with SAAs and DBs was selected from historically well-known outburst-hazardous seams k_7 ("Smolyaninovsky") and m_2 ("Tonky"), their impact safety coefficient ranged between 0.4 and 0.6. Meanwhile, the impact safety coefficient of seam d_4, provided under the conditions of Pokrovske Mine Administration for experiments with “the Shtamex”, turned out to be significantly lower — around 0.1 to 0.2. That is, this coal was much more hazardous not only compared to Donetsk coal but also compared to the average Pokrovske seam, as our previous experiments with it did not reveal such a “bouquet” of anomalies. Thus, it is not surprising that “the Shtamex” solution did not raise the safety of this highly hazardous coal to a safe level

A more objective assessment of the effect of “the Shtamex” solution on the outburst safety of coal is given by comparing the ratios of the impact safety coefficients of coal before and after its treatment. For water, this ratio is ≈ 1.8, for 3% “the Shtamex” solution it is ≈ 1.5, and for 6% “the Shtamex” solution it reaches ≈ 4. For traditional SAAs, this ratio is within 1.5–1.9.

Thus, the effectiveness of “the Shtamex” solution at a concentration of 4% is at the level of water and traditional antipyrogens, and at a concentration of 6% - it is twice as high.

However, this effect is achieved at the cost of a 30-fold increase in “Shtamex” concentration compared to traditional SAAs solutions, which may significantly raise the cost of coal seam treatment.

In this regard, the practical feasibility of using emulsions from mine support hydraulic systems instead of water or aqueous solutions of traditional SAAs, antipyrogens, and foaming agents remains an open question. In which cases is their application economically justified?

The results of the conducted studies allow us to determine the area of indisputable advantage of using aqueous solutions of chemicals. This is the treatment of sectors of the seam with very low outburst safety combined with excessive water permeability.

This was exactly the coal from seam d_4 provided by the Pokrovske Mine Administration for experiments with “the Shtamex” foaming agent:

First, it had a very low impact safety index - at the level of 0.1–0.2, whereas previous samples from the same seam d_4 that we received in earlier years (2022) showed a minimum value of 0.3–0.4 only in 2 out of 7 samples, with 4 others ranging within 0.6–0.7, and one reached 1. And for the historically well-known outburst-hazardous seams k_7 - "Smolyaninovsky" and m_2 - "Tonky", samples of which were previously tested by the IGTM, the impact safety coefficient was within 0.4–0.6.

Second, the permeability of the received coal for water turned out to be so high that it made impossible the crucial process of its flow saturation with water under normal pressure gradient (at least 0.15 MPa) between the cleavage cracks and the rest of the seam.

Under these circumstances, the only way forward is to use chemical additives. Moreover, the decisive parameter of the solution is increasing its viscosity. The selection of chemicals that, on the one hand, increase the viscosity of the aqueous solution, and on the other hand, increase the impact safety of coal is an urgent task for further research.

4. Conclusions

The effect of moistening with “Shtamex” on the growth of longitudinal deformation at the same stresses (i.e. the increase in coal yield) is 1.3–1.4 times greater than the increase caused by ordinary water and by emulsion for mine hydraulic systems. This makes “Shtamex” a more effective means of local unloading the coal seam from excessive rock pressure.

The effectiveness of “the Shtamex” solution for increasing the outburst safety indicator at its concentration of 4% is at the level of water and traditional antipyrogens, while at a concentration of 6%, it exceeds them twofold.

The area of indisputable advantage of using aqueous solutions of chemicals is the treatment of coal seam sections with very low outburst safety combined with excessive water permeability. And their decisive characteristic of the solution is the increase in its viscosity.

The scientific value of this work lies in advancing the understanding of the influence of fluid injection into coal seams on their deformation characteristics and outburst safety index.

The practical value of the work lies in reducing the probability of sudden coal outbursts, which cause significant economic losses and pose serious threats to the lives and health of underground workers.

Conflict of interest

Authors state no conflict of interest.

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ДОСЛІДЖЕННЯ ВПЛИВУ НАСИЧЕННЯ ВУГІЛЬНИХ ЗРАЗКІВ РОЗЧИНОМ ПІНОУТВОРЮВАЧА «STHAMEX» НА ПОКАЗНИКИ ЇХ ВИКИДОНЕБЕЗПЕКИ

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Анотація. У статті наведені результати досліджень механічних параметрів зразків вугілля пласта d_4 з ПрАТ «Шахтоуправління «Покровське» в стані постачання та після обробки розчином піноутворювача “Shtamex”. Дослідження показали, що ці зразки вугілля відрізнялися дуже високою викидо небезпечністю, порівняно з іншими зразками того ж пласта. Крім того вони мали аномально високу водопроникність. Одержані деформаційні лінії, які виражають зв’язок між механічними напруженнями і деформаціями при одновісному стисканні зразків кубічної форми з розміром ребра 40 mm з центральним отвором діаметром 6 mm. Отвори були просвердлені перпендикулярно нашаруванню зразків. В тому ж напрямку здійснювалось їх навантаження. Модуль пружності (податливість) сухих зразків оцінювалась по деформаційних лініях з обмеженим навантаженням не більшим 5 МПа – на рівні 30–40% від передбачуваного максимального. Обмеження навантаження мінімізувало вплив порушення суцільності зразка внаслідок початку процесу утворення тріщин. податливість) сухих зразків оцінювалась по деформаційних лініях повного навантаження тих самих зразків. Повне навантаження включало ділянку зростання напружень, перехід через тимчасову межу міцності і ділянку спаду аж до руйнування зразків. Коефіцієнт викидо (ударної) безпечності обчислювався як співвідношення модулю пружності до модулю спаду напружень за тимчасовою межею міцності. Аномально висока водопроникність зразків унеможливила їх насичення розчином “Shtamex” за стандартною методикою ІГТМ в режимі проточної двовимірної фільтрації від периферії до центрального отвору. Воно здійснювалося менш ефективним шляхом витримки зразків протягом 45 хвилин під надлишковим тиском 0,15 МПа. В період витримки здійснювалися 2–3 короткочасних спуска суміші частини розчину через центральний отвір зразка та дренажний канал. Встановлено, що насичення зразків розчином “Shtamex” знижує модуль пружності, тобто підвищує податливість вугілля. В цьому плані ефект від “Shtamex”подібний до ефекту від води, традиційних ПАР та емульсії. Але приріст податливості від “Shtamex”, як мінімум в 1,3 рази вищий за приріст від води, традиційних ПАР та емульсії. Так же як вода, традиційні ПАР та емульсія “Shtamex” підвищує коефіцієнт викидо безпечності. Підвищення викидо безпеки при 3% концентрації “Shtamex” знаходиться на рівні води та традиційних ПАР, а при 6% концентрації “Shtamex” становиться майже вдвічі більш ефективним за них.

Ключові слова: податливість, тимчасова межа міцності, модуль спаду, викидонебезпека.